

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE (DD-MM-YYYY) 11/09/2018		2. REPORT TYPE Journal		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Chronic Decompression Illness Cognitive Dysfunction Improved with Hyperbaric Oxygen: A Case Report				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Wolf, Earl George				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) 59th Clinical Research Division 1100 Willford Hall Loop, Bldg 4430 JBASA-Lackland, TX 78236-9908 210-292-7141				8. PERFORMING ORGANIZATION REPORT NUMBER 17496	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) 59th Clinical Research Division 1100 Willford Hall Loop, Bldg 4430 JBASA-Lackland, TX 78236-9908 210-292-7141				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.					
13. SUPPLEMENTARY NOTES Undersea and Hyperbaric Medicine					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Clarice Longoria
					19b. TELEPHONE NUMBER (Include area code) 210-292-7141

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3 **Chronic decompression illness cognitive dysfunction improved with hyperbaric oxygen: a**
4 **case report**

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11 Running head: Chronic DCI cognitive dysfunction improved with HBO2

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Chronic decompression illness cognitive dysfunction improved with hyperbaric oxygen: a case report

Introduction

Altitude chamber exposures are used for training to allow aircrew to experience their hypoxia and pressure effect symptoms. Decompression illness (DCI) is an umbrella term that includes decompression sickness and/or air gas embolism, both known complications that can occur subsequent to altitude chamber training or in operational aircraft when the cabin altitude is at least 18,000 feet. Compared to open water diving, the incidence of altitude chamber induced decompression illness is around 0.25% (1). Because the evolution of gas within the tissue or vasculature is being treated upon recompression from altitude reaching the surface, often these DCI symptoms will decrease or resolve altogether. Residual joint pain may be treated by breathing 100% oxygen, preferably using an aviator's mask or a continuous positive airway pressure mask. If not available, at the very least, a non-rebreather may be used, but in the best of conditions may supply around 60% inhaled oxygen. If the symptoms resolve, the patient remains on 100% oxygen for one hour longer or a minimum of two hours whichever is longer. If joint pain symptoms do not resolve by two hours, if the initial symptoms were neurological, or if any resolved symptoms recur, then recompression in a hyperbaric chamber is warranted where a US Navy treatment table 6 (TT6) is most often used for therapy. Alternate tables are available at the discretion of the hyperbaric medicine physician or chamber dive master. If symptoms persist, additional treatment "tailing dives" using US Navy treatment table 5, 6 or a treatment table 9 (45 feet of sea water (137.8 kPa) with a 30 minute oxygen period separated by a period of air breathing – a standard hyperbaric wound treatment profile) are done daily until symptoms resolve or plateau over two successive treatments.

Patient history

A 27-year-old female underwent altitude chamber training to an altitude of 25,000 feet on 26 June 2012. During the hypoxia demonstration, she experienced onset of tingling in both legs and left arm, in addition to headache, dizziness, and malaise. The physiological technicians in the chamber ensured that she started breathing 100% oxygen but her symptoms continued. She then started having difficulty responding to the attendants. She could hear them, but could not speak back. Upon compression to surface, she was examined by the local flight surgeon who confirmed her symptoms and noted she had photophobia. The patient was transported to a hyperbaric facility and received a USN treatment table 6 hyperbaric treatment. Upon returning home, she experienced new onset right hip pain (4-5/10 pain at rest) with continued headache, dizziness and generalized malaise. She visited flight medicine the next day and was transported back to the hyperbaric facility. She underwent a tailing TT5 due to right hip pain development and continued headache, and dizziness as well as a perception of decreased mental capacity. Post treatment, her symptoms resolved except for a continued moderate headache. She returned home and sent back to her unit, but not returned to flying status. The patient continued to have recurrence of intermittent paresthesia and decreased memory over the next 12 months. Her cognitive function worsened slowly over time described by her as similar to mild to moderate traumatic brain injury symptoms. The patient was evaluated by neurology, psychiatry, psychology, and aerospace medicine specialists for the continued symptoms including decreased executive function and reaction times. The brain MRI was unremarkable and normal. In addition, her echocardiogram for potential patent foramen ovale demonstrated no shunting. Medications during this time included topiramate, combination isometheptene, acetaminophen and dichloralphenazone (Midrin), combination butalbital, acetaminophen, caffeine (Fioricet), rizatriptan and naproxen for headache, trazodone for sleep issues, and sertraline for depression.

1 Eventually, she was referred 14 months after the incident to Wilford Hall Ambulatory Surgical
2 Center Undersea and Hyperbaric Medicine for further evaluation.

3 4 **Materials and Methods**

5 As the patient deployed multiple times, she had a number of Automated
6 Neuropsychological Assessments Metrics (ANAM) tests (2). ANAM was developed by the U.S.
7 Army in the late 1990's using computer based cognitive measures and tests including attention,
8 concentration, reaction time, memory, processing speed, decision-making and executive
9 function. Prior to her acceptance for treatment another ANAM was administered to create a pre-
10 treatment baseline on 25 June 2013. This was compared to her most recent pre-deployment
11 ANAM result on 20 March 2012 (Fig 1 and 2). After local evaluation, the patient started twice
12 daily (7 AM and 1 PM) treatments at a compression depth of 2.0 atmospheres absolute. Serial
13 ANAM tests were done after every 10 treatments (weekly) and compared to the pre-treatment
14 baseline and her 20 March 2012 ANAM scores. These ANAM results described in this report
15 are compared using the tests administered on, 10 October 2013 (post 20 treatments), and the final
16 ANAM on 5 November 2013 (39 total treatments).

17 18 **Results**

19 The ANAM on 20 March 2012 demonstrated "average or above" performance scores in
20 all seven subtests with a sleep score of 2, and mood scores as seen in Fig 1. On 25 June 2013
21 performance scores were "clearly below" except for the "matching to sample" test, which was
22 "below average" with a sleep score of 2 and considerable worsening in all mood scores (Fig 2).
23 The serial ANAM scores improved over the first 20 treatments as seen in the ANAM on 10
24 October 2013 (Fig 3) with all performance scores "average or above" except for the two reaction

time scores (“below average” and “clearly below”) with a sleep score of 1 and improved mood scores. She had an 11 day break to return to her home base. An ANAM was done prior to restarting hyperbaric treatments on 21 October 2013. The results demonstrated a slight deterioration with four performance scores “average or above” and three “below average” with a sleep score of 3 and some decreases in all of the mood scores except “restlessness, anxiety, and anger”. The final ANAM on 5 November 2013 (Fig 4, post 39 total treatments) showed the performance scores “average or above” in all of the domains except for reaction time (“below average” and “clearly below”). These were nearly the same as the predeployment ANAM on 20 March 2012, and greatly improved compared to the pretreatment baseline ANAM on 25 Jun 13. The sleep score was 1 and the mood scores approached those of the predeployment ANAM and considerably improved from the pretreatment baseline ANAM.

Discussion

The symptoms from the altitude exposure favor air gas embolism with continued symptoms similar to traumatic brain injury from blast injuries as air emboli are produced (3-7). Both causes of air embolism recommend hyperbaric oxygen.

In spite of initial hyperbaric oxygen therapy the cognitive symptoms continued to worsen over time. Upon home base evaluation there was no shunting across the intra-atrial septum and MRI studies failed to demonstrate any pathological lesions. A pulmonary etiology could have occurred. One study of the potential use of hyperbaric oxygen for traumatic brain injury suggested a more likely benefit when symptoms were treated within 2 years of the precipitating event (8 - national meeting data presentation done June 2013). Based on this, we felt the residual DCI symptoms warranted treatment even though they initially occurred 14 months prior.

1 The protocol developed was based on neurological decompression sickness treatment where
2 hyperbaric oxygen therapy is continued until the symptoms resolve or plateau. Unfortunately,
3 the time frame was based on the number of days her base approved her temporary duty as a
4 patient. This precipitated the twice daily hyperbaric exposures versus single day exposures and
5 longer time to complete the same number of treatments. However, twice a day treatments are
6 common in acute hyperbaric oxygen indications and are used on occasion in late effect of
7 radiation injury cases (9). This demonstrates the issue of basing hyperbaric oxygen treatments to
8 patient response in conjunction with symptom changes, laboratory or other testing as a guide to
9 the therapy utilization.

10 In this case, we had an objective measure (ANAM) administered after every 10 treatments. The
11 ANAM is designed for repeated measures testing (10), but training effect is a concern in such
12 tests. Eonta (11) demonstrated improvement in repeated tests given back to back on the same
13 day, but plateauing over the last 2 days (3 and 4-day studies). In this case report, it could be a
14 factor, but likely small, as the 10-day break demonstrated a deterioration in scores followed by
15 improvement. In addition, interval tests had individual subtests that had positive and negative
16 changes, but with overall improvement throughout the course of treatment. Placebo effect due to
17 “medical vacation” cannot be ruled out; however, the patient was in medical hold at her home
18 base and not performing an active job. The demonstration that hyperbaric oxygen results in stem
19 cell mobilization due to hyperbaric oxygen therapy may be a factor in the patient’s overall
20 cognitive improvement (12).

21
22 Would the patient improve without hyperbaric oxygen? Certainly, she may have. However, her
23 four pre-deployment ANAM performance scores were “average or above” in all domains and the
24 significant deterioration post incident seen in the 25 June 2013 pre-treatment scores could not

1 have been much worse. As the base ANAM consultant observed, the case demonstrated real
2 changes beyond mere “training effect”. How much hyperbaric oxygen therapy was increasing
3 the slope of improvement is the question. The patient was at risk of discharge from the service
4 from a medical evaluation board prior to her treatment. At last check, she remained on active
5 duty.

6 7 **Summary**

8 This altitude training DCI case resulting in chronic cognitive dysfunction is the first case
9 to our knowledge that has been treated well after the normal timeframe. The availability of pre-
10 incident cognitive function testing allowed us to objectively measure improvement during the
11 hyperbaric oxygen therapy series. Such monitoring can be done, especially when a baseline is
12 available. This has potential impact for similar cognitive neurological cases in diving and
13 altitude as well as other bubble-related etiologies, including surgical-induced air gas emboli and
14 blast injury (13).

15 **Disclaimer:** The views expressed are those of the authors and do not reflect the official views or
16 policy of the Department of Defense or its Components.

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HISTORY

Injury cause(s):

Resulting in:

Symptoms Right after Injury: none recorded.

None recorded.

None recorded.

Symptoms Now While Resting: none recorded.

Symptoms Now after Exertion: none recorded.

PROVIDER OBSERVATIONS

MACE:

Interval between current and previous injury:

PERFORMANCE AT A GLANCE

Comparison Group: Military:
All Services Females Age 26-30

Comparison to BASELINE	SCALE (DOMAIN)	AVERAGE OR ABOVE	BELOW AVERAGE	CLEARLY BELOW
<input type="checkbox"/>	Simple Reaction Time (REACTION TIME)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	Simple Reaction Time (R) (REACTION TIME)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	Procedural Reaction Time (PROCESSING SPEED)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	Code Substitution - Learning (LEARNING)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	Code Substitution - Delayed (DELAYED MEMORY)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	Mathematical Processing (WORKING MEMORY)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	Matching to Sample (SPATIAL MEMORY)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SLEEP (1-7)

Score: 2 - Able to concentrate, but not quite at peak.

MOOD (0-100)

81 HAPPINESS
69 VIGOR
08 FATIGUE
00 RESTLESSNESS
00 ANXIETY
00 DEPRESSION
00 ANGER

REFERENCE

Category lower limits for Below Average (9th percentile, 80.5 standard score) and Clearly Below Average (2nd percentile, 70 standard score) are based on Hannay, H. J., & Lezak, M. D. (2004). The neuropsychological examination: Interpretation. In M. D. Lezak, D. B. Howieson, & D. W. Loring (Eds.), *Neuropsychological Assessment* (pp. 133-156). New York: Oxford University Press.

1

2 Figure 1. ANAM on 20 March 2012

3

HISTORY

Injury cause(s):

Resulting in:

Symptoms Right after Injury: none recorded.

None recorded.

None recorded.

Symptoms Now While Resting: none recorded.

Symptoms Now after Exertion: none recorded.

PROVIDER OBSERVATIONS

MACE:

Interval between current and previous injury:

PERFORMANCE AT A GLANCE

Comparison Group: Military:
All Services Females Age 26-30

Comparison to BASELINE	SCALE (DOMAIN)	AVERAGE OR ABOVE	BELOW AVERAGE	CLEARLY BELOW
<input type="checkbox"/>	Simple Reaction Time (REACTION TIME)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/>	Simple Reaction Time (R) (REACTION TIME)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/>	Procedural Reaction Time (PROCESSING SPEED)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/>	Code Substitution - Learning (LEARNING)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/>	Code Substitution - Delayed (DELAYED MEMORY)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/>	Mathematical Processing (WORKING MEMORY)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
<input type="checkbox"/>	Matching to Sample (SPATIAL MEMORY)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

SLEEP (1-7)

Score: 2 - Able to concentrate, but not quite at peak.

MOOD (0-100)

44 HAPPINESS
47 VIGOR
56 FATIGUE
39 RESTLESSNESS
56 ANXIETY
56 DEPRESSION
33 ANGER

REFERENCE

Category lower limits for Below Average (9th percentile, 80.5 standard score) and Clearly Below Average (2nd percentile, 70 standard score) are based on Hannay, H. J., & Lezak, M. D. (2004). The neuropsychological examination: Interpretation. In M. D. Lezak, D. B. Howieson, & D. W. Loring (Eds.), *Neuropsychological Assessment* (pp. 133-156). New York: Oxford University Press.

1

2 Figure 2. ANAM on 25 June 2013

HISTORY

Injury cause(s):

Resulting in:

Symptoms Right after Injury: none recorded.

None recorded.

None recorded.

Symptoms Now While Resting: none recorded.

Symptoms Now after Exertion: none recorded.

PROVIDER OBSERVATIONS

MACE:

Interval between current and previous injury:

PERFORMANCE AT A GLANCE

Comparison Group: Military:
All Services Females Age 26-30

Comparison to BASELINE	SCALE (DOMAIN)	AVERAGE OR ABOVE	BELOW AVERAGE	CLEARLY BELOW
-2.83	Simple Reaction Time (REACTION TIME)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
-2.34	Simple Reaction Time (R) (REACTION TIME)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
-2.7	Procedural Reaction Time (PROCESSING SPEED)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
0.99	Code Substitution - Learning (LEARNING)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
0.32	Code Substitution - Delayed (DELAYED MEMORY)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
-0.62	Mathematical Processing (WORKING MEMORY)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
-0.63	Matching to Sample (SPATIAL MEMORY)	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SLEEP (1-7)

Score: 3 - Relaxed and awake, but not fully alert.

MOOD (0-100)

58 HAPPINESS
47 VIGOR
42 FATIGUE
22 RESTLESSNESS
31 ANXIETY
25 DEPRESSION
08 ANGER

REFERENCE

Category lower limits for Below Average (9th percentile, 80.5 standard score) and Clearly Below Average (2nd percentile, 70 standard score) are based on Hannay, H. J., & Lezak, M. D. (2004). The neuropsychological examination: Interpretation. In M. D. Lezak, D. B. Howieson, & D. W. Loring (Eds.), *Neuropsychological Assessment* (pp. 133-156). New York: Oxford University Press.

1

2 Figure 3. ANAM on 10 October 2013

HISTORY

Injury cause(s):

Resulting in:

Symptoms Right after Injury: none recorded.

None recorded.

None recorded.

Symptoms Now While Resting: none recorded.

PROVIDER OBSERVATIONS

MACE:

Interval between current and previous injury:

Symptoms Now after Exertion: none recorded.

PERFORMANCE AT A GLANCE

Comparison Group: Military:
All Services Females Age 26-30

Comparison to BASELINE	SCALE (DOMAIN)	AVERAGE OR ABOVE	BELOW AVERAGE	CLEARLY BELOW
-1.85	Simple Reaction Time (REACTION TIME)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
-4	Simple Reaction Time (R) (REACTION TIME)	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
-1.47	Procedural Reaction Time (PROCESSING SPEED)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
-0.06	Code Substitution - Learning (LEARNING)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
0.42	Code Substitution - Delayed (DELAYED MEMORY)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
0.01	Mathematical Processing (WORKING MEMORY)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
-1.07	Matching to Sample (SPATIAL MEMORY)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SLEEP (1-7)

Score: 1 - Feeling very alert, wide awake, and energetic.

MOOD (0-100)

56 HAPPINESS
67 VIGOR
19 FATIGUE
14 RESTLESSNESS
36 ANXIETY
08 DEPRESSION
06 ANGER

REFERENCE

Category lower limits for Below Average (9th percentile, 80.5 standard score) and Clearly Below Average (2nd percentile, 70 standard score) are based on Hannay, H. J., & Lezak, M. D. (2004). The neuropsychological examination: Interpretation. In M. D. Lezak, D. B. Howieson, & D. W. Loring (Eds.), *Neuropsychological Assessment* (pp. 133-156). New York: Oxford University Press.

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2 Figure 4. ANAM on 5 November 2013

3